VIA MEDICA

Vol. 7, No. 2, pp. 177–182

ISSN 1506–9680

Review

Veterinary nuclear medicine

Marcin Krzemiński[1], Piotr Lass[2], Jacek Teodorczyk[2], Jarosława Krajka[3]

[1]Veterinary Hospital Łąkowa, Gdańsk, Poland
[2]Department of Nuclear Medicine, Medical University, Gdańsk, Poland
[3]Department of Eye Diseases, Medical University, Gdańsk, Poland

[Received 8 XI 2004; Accepted 17 XI 2004]

Introduction

The veterinary use of radionuclide techniques dates back to the mid-sixties [1, 2], but its more extensive use dates back to the past two decades. In Central and Eastern Europe, it is still in its infancy with only one large research centre, in Budapest, Hungary.

Veterinary nuclear medicine is focused mainly on four major issues: bone scintigraphy — with the majority of applications in horses, veterinary endocrinology — dealing mainly with the problems of hyperthyreosis in cats and hypothyreosis in dogs, portosystemic shunts in small animals and veterinary oncology, however, most radionuclide techniques applied to humans can be applied to most animals.

There is little awareness of the usefulness of radionuclide studies in veterinary practice among the nuclear medicine community. Therefore, we decided to describe some of its applications.

Clinical applications

Bone scintigraphy

Its main objectives are horses, dogs, and to a lesser extent, cats. The demand for advanced and correlative imaging methods in equine medicine is growing. Scintigraphy can provide unique information about the physiological status of an animal that cannot be discerned by other imaging modalities. The crucial problem in horses, where traditional radiographic techniques may not be sufficient, are leg and neck bone lesions, in the second row a veterinary oncology.

Correspondence to: Piotr Lass
Department of Nuclear Medicine, Medical University
ul. Dębinki 7, 80–211 Gdańsk, Poland
Tel./fax: (+48 58) 349 22 04
e-mail: plass@amg.gda.pl

Orthopaedic applications

Bone scintigraphy offers the major advantage of increased sensitivity over standard radiographic imaging. Except for consistent identification of bone cysts, most of the pathological changes to the horse's musculoskeletal system that might cause lameness can be detected using bone scans. Many acute bone diseases can be diagnosed by scintigraphy that cannot be discerned by radiographs until the condition has become chronic. Because of their body size, these conditions may not be diagnosed in horses at all. Scintigraphy in horses offers the other major advantage of affording accurate imaging of the upper limbs, pelvis, and vertebral column without general anaesthesia. Therefore, it has the final advantage of increased safety over conventional radiography because it eliminates the need to perform general anaesthesia to study these areas. A second major benefit of scintigraphic imaging is to differentiate mixed lameness conditions, in which the component of bone disease must be separated from that of soft tissue to arrive at a rational course of treatment or prognosis. Finally, for athletic horses suspected of having lameness due to localized myositis, scintigraphy not only allows confirmation of muscle inflammation, but also identifies the injured muscle bellies reasonably and accurately, so that specific local treatment may be given. Nuclear imaging of equine skeletal disease is an option that should be employed more frequently by equine practitioners for diagnosis of difficult lameness cases. The technique is safe and comparatively inexpensive when one considers the total expense of multiple examinations or radiographic surveys of patients without conclusively diagnosing the source or sources of skeletal pain. This is particularly true when a horse owner becomes dissatisfied and enlists the services of one or more other veterinarians. The equine specialist will maintain better client rapport if he or she suggests referral of the horse to a veterinary medical teaching centre or private clinic where scintigraphic imaging can be carried out, rather than having the client become frustrated and seek another opinion elsewhere [3].

An important cause of lameness in horses, where scintigraphic imaging may be considered, can be stress fractures of legs [4]. Stress fractures of scapula with positive RN and negative radiographic imaging also can be met [5].

Lameness detection is also a major problem of, so-called, veterinary sports medicine, i.e. evaluating the problems of equine (or canine) athletes. It should be remembered, however, that the poor performance of animal athletes could be the result not only of orthopaedic problems, but also of upper and lower airway function disturbances, which result in increased resistance to airflow — a major cause of poor racing performance. Scintigraphic imaging modalities can be used to evaluate both global and regional lung function in cases of suspected pneumonia, chronic obstructive pulmonary disease or emphysema. Nuclear medicine studies can often offer some help in these situations [6]. In some cases, bilateral lameness can be the result of aortoiliac thromboembolism, detectable with first-pass radionuclide angiography [7].

Bone scintigraphy may also be used in the detection of occult lameness in dogs [8]. Scintigraphy has also gained wide acceptance in diagnosing elbow dysplasia. The term elbow dysplasia encompasses a variety of developmental abnormalities that affect the elbow. Some of the more common conditions referred to as elbow dysplasia include dissecant osteochondrosis, non-united anconeal process, fragmented coronoid process and premature closure of the ulna. Scintigraphy helps to diagnose joint incongruity that has not yet developed into a condition that is detectable by radiography. In addition, scintigraphy has proven helpful in localizing lesions in the shoulder, elbow, stifle, and tarsal joints associated with osteochondrosis and osteoarthritis [9]. In some cases, radionuclide technique could be used in disorders secondary to vertebral column lesions; for example there are reports on scintigraphy performed in bulls with decreased libido due to painful lesions of the vertebral column. Radiographic evaluation of vertebral skeletal problems in mature bulls is limited because of high body mass. Bone scintigraphy helped to determine the location of vertebral column lesions and facilitate localized treatment [10]. Scintigraphy should be considered in all cases of animal lameness which cannot be diagnosed by conventional methods. This technique is also useful as an early indicator of the disease, not only as a method of "last hope" [11].

Oncologic bone scintigraphy applications

In veterinary oncology, the principal goal is the detection of osteosarcoma [12–16]. In limb sarcoma, both radiography and scintigraphy tend to overestimate its extent when compared with histopathologic macro-slides of the same lesions. Nuclear scintigraphy overestimates tumour extent to a larger degree than does radiography. Although radiography is a more accurate method of measurement of the extent of distal radius osteosarcoma, scintigraphy may provide a larger margin of safety for determining the site of proximal osteotomy during a limb-salvage procedure. However, caution should be exercised when utilizing scintigraphy, because this method may overestimate the length of radius involved to such an extent as to cause the surgeon to believe that a patient is not a suitable limb-salvage candidate [13].

An interesting finding is the extra-skeletal accumulation of osteotropic radiotracers of osteosarcomas in cats and dogs [14–16]. This might have some therapeutic importance, as the therapeutic radiotracers: strontium-89 and samarium-153-EDTMP were also showed to accumulate in extraosseous sarcomas [17].

The detection of primary and metastatic osteosarcoma has been also attempted with immunoscintigraphy using F(ab')2 fragments of osteosarcoma-associated monoclonal antibody TP-1 [18].

Veterinary oncology

Oncophilic agents such as 99m-technetium MIBI and DMSA(V) have proven to be useful in detecting lymphomas and malignant schwannomas [19].

As in humans, there is a proven usefulness of sentinel node detection in oncologic patients [20]. Balogh et al proved the superiority of pre-operative RN sentinel node detection (89%) and intraoperative radioguided surgery (97%) over blue-dye technique (77%).

Veterinary endocrinology

Most nuclear medicine procedures in this field are related to thyroid gland diagnostics and therapy, both in dogs and cats. Hyperthyroidism is a crucial problem in cats, and hypothyroidism in dogs.

Feline hyperthyroidism was first described in 1979 and is a relatively common disease. Its symptoms and signs are, as in humans, chronic weight loss, intermittent dyspnoea, chronic diarrhoea, hyperactivity and weakness [21]. Diagnosis, as in humans, is based on palpation, scintigraphy and ultrasound. Management, again as in humans, is either with thyreostatic agents, surgical or with radioiodine, and sometimes even with ethanol ablation.

Thyroidal isotope uptake and scintigraphy

Uptake of radioactive iodine (131-I or 123-I) and 99m-technetium as pertechnetate is increased in hyperthyreoidal cats [22, 23]. Qualitative scintigraphic imaging is a useful procedure to determine unilateral or bilateral involvement, alterations in the position of thyroid lobes, the site of hyperfunctioning accessory or ectopic thyroid tissue, or distant metastases from a functioning thyroid carcinoma [24]

Radioiodine treatment

Radioiodine therapy of hyperthyroidism in cats is a very important issue. It is considered to be the safest, simplest and most effective therapy of feline hyperthyroidism [23].

A target delivery dose to the thyroid is 150 Gy. The average activity of radioiodine applied varies from 3–5 mCi. It is administered orally, intravenously or subcutaneously. The two latter means of radioiodine administration are preferable, but when compared with i.v. administration, s.c administration of radioiodine appears to be safer to personnel, less stressful to the cats and it is currently the preferred route of administration of radioiodine [25]. Oral administration was attempted, but higher doses are generally required, the risks of radiation spillage are greater and vomiting may occur. Euthyroidism may be attained in over 90% of cases with a single dose ranging from 39 to 222 MBq [23, 27]. Regarding survival time following treatment of hyperthyroidism with radioiodine, 67% of cats were alive and euthyroid up to 33 months after treatment [29]. Many of the remaining cats died due to renal disease, which could be a side-effect of the treatment (see section below). Hypothyroidism and recurrent hyperthyroidism can develop, but seem to be fairly rare; other side effects are minimal [26].

The main drawbacks to widespread use of radioactive iodine treatment in cats are the requirements for special licensing and the need of isolation of the cats following treatment, ranging from a several days to several weeks depending on the dose used and local radiation regulations.

Radioiodine treatment of hyperthyroidism in cats — renal disease as a side-effect

Hyperthyroidism itself can mask underlying renal disease [30]. Also the renal function may further be adversely affected by the induction of euthyroidism and should be carefully evaluated before treatment with radioiodine [23]. Renal-irradiation due to radioiodine renal excretion cannot also be excluded. Renal side-effects care is also required for treatment with anti-thyroid drugs and surgery. A significant decline in renal function may frequently occur after the treatment of hyperthyroidism in cats with previous renal disease, therefore pre-treatment measurement of GFR is valuable in detecting sub-clinical renal disease and in predicting which cats may have clinically important declines in renal function following treatment [30]. In the absence of such estimations, careful evaluation of serum urea and creatinine concentrations and urine specific gravity is required before radioiodine treatment of hyperthyroidism [23].

Radioiodine treatment of hyperthyroidism in cats — radioprotection of staff and environment

Just as in humans, a crucial factor is the radioprotection of staff securing radioiodine-treated cats, due to the radioactivity of the animals themselves and their urine. The effective decay half-time after oral administration of 178 to 204 MBq of 131-I (T1/2E) for surface emissions was 2.19 to 4.70 days, and T1/2E for urine radioactivity was 2.16 to 3.67 days. Surface gamma-radiation emission rates for cats following administration of I-131 appears useful in determining the upper limits (threshold) of urine radioactivity and are a valid method to assess the time at which cats can be discharged after I-131 administration [31]. In the USA, it varies between 3–7 days. In Germany, it requires hospitalization for approximately two weeks, although the practical considerations of radiation exposure of cat owners do not justify this long interval [32]. On the other hand, cats seem to tolerate the period of hospitalisation relatively well.

Hypothyroidism

Hypothyroidism is a relatively frequent disorder in dogs. Underlying causes include thyroid dysgenesis and inherited iodination defects. Scintigraphy readily differentiates between those two conditions because animals with thyroid dysgenesis have minimal uptake of radionuclides in the anatomic region of the thyroid gland, whereas animals with iodination defects have enlarged thyroid lobes with normal or increased tracer uptake [33]. In thyroid carcinoma and associated hypothyroidism, scintigraphy helps to localize the lesion, and thus allows adequate planning for surgical resection and later for post operative evaluation [34]. Radionuclide therapy was also reported in animal thyroid carcinoma [35].

Other endocrine disorders

99m-technetium sestamibi may be use for the detection of a parathyroid adenoma in dogs with primary hyperparathyroidism [36].

Somatostatin receptor scintigraphy using indium In-111 pentatreotide can be performed in APUDoma tumours — this is important, because these tumours, in dogs, have a poor long-term prognosis due to a high rate of metastases and recurrence; staging (and therefore prognosticating) is difficult and usually done at the time of surgery [37, 38].

Cardiology

Equilibrium gated blood pool study proved to be useful in dogs with an X-linked, Duchenne-like, muscular dystrophy involving myocardium, the same as human Duchenne muscular dystrophy [39].

Nuclear scintigraphy with 99mTc-MAA proved to be a quick alternative method to cardiac catheterization in diagnosing right-to-left cardiac shunts and quantification of shunt fraction [40].

In peripheral vessels, first-pass radionuclide angiography proved to be useful in detecting aortoiliac thrombosis [7].

Lungs

Conventional perfusion scintigraphy has the similar indications, acquisition mode and outcomes as in humans [41].

Ventilation/perfusion scintigraphy in horses provides valuable additional information on regional lung function that is not obtainable from conventional thoracic radiographs. This is particularly true of horses with chronic obstructive pulmonary disease and those suspected of having some form of small-airway disease. Findings from horses with chronic obstructive pulmonary disease have improved the understanding of the radiographic patterns of air trapping and vascular distribution, and provided us with a sensitive means of detecting residual bronchial changes in the absence of clinical signs of the disease. Several other scintigraphic parameters such as mucociliary clearance and abscess-avid labelling show promise for future lung imaging on clinical cases, but still require further research to develop appropriate techniques for delivery and image analysis [42].

Gastrointestinal tract and kidneys

GI tract

Probably radionuclide diagnosis of portosystemic shunts (PSSs) in cats and dogs is most important here.

Portosystemic shunts (PSSs) are abnormal venous communications allowing blood in the portal system to enter the systemic venous system directly, without passing the liver. The shunted blood contains abnormally high levels of compounds absorbed from the intestinal tract that are normally removed, detoxified or metabolised by the liver [43]. Shunts are classified as intra- and extra-hepatic, or, alternatively, as congenital or acquired. Most feline congenital PSSs consist of a single large vessel representing a developmental error in which a vascular communication is maintained between abdominal veins derived from the cardinal and vitelline veins. Extrahepatic shunts are located outside the liver parenchyma and most commonly empty into the prehepatic *vena cava*. However, some cats may have atypical PSS connections. The clinical signs in dogs and cats with portosystemic shunts are highly variable, but usually involve poor growth and central nervous system signs of postprandial hepato-encephalopathy. These central nervous system signs may include intermittent disorientation, pacing, circling, tremors and even seizures. Congenital shunts are best managed with surgical intervention, where acquired need medical treatment. To accomplish this task, veterinarians must be able to identify patients in which a PSS is a strong possibility.

Transcolonic portal scintigraphy is a non-invasive method of diagnosing PSS and also allows calculation of the shunt degree, although scintigraphy, unlike jejunal vein portography, cannot aid in precise anatomic shunt localization. With a cat under sedation, 99m-technetium (usually as DTPA compound) is placed into the colon where it is rapidly absorbed into the portal system. In an animal with normal portal circulation, the liver field is the first marked by a radionuclide flow; in PSS, the area represented by a liver is a void, whereas the heart is the first organ illuminated by the radiotracer flow [43].

Surgical options for PSS occlusion include ligation for acute vessel occlusion and for slow vessel occlusion using an ameroid constrictor. The prognosis is based on the degree of shunt occlusion and the ability of the liver to adapt to increased hepatic blood flow [43]. However, post-operation mortality is high.

The opinions on hepatobiliary scintigraphy with HIDA derivates are controversial. Whereas some authors advocate this method in lambs [44], dogs and cats [45], the others say that the method is insensitive in cholangiohepatic lesions [46]. Quantitative hepatobilliary scintigraphy facilitates the interpretation of the study [47].

Kidneys

In cats and dogs, renal insufficiency is relatively frequent. There are number of diseases that can affect the kidneys in animals, which include: infections, neoplasms, cysts, nephrolithiasis, and injury from toxin exposure (glycol antifreeze, aspirin, acetaminophen, ibuprofen), as well as a number of inflammatory diseases (glomerulonephritis, systemic lupus). Diagnosis of kidney disease is difficult in the stage of compensation, and impossible when based solely on routinely performed laboratory tests of blood and urine. As in humans, only scintigraphy allows unilateral assessment of renal function, which is most important in animals with morphologically altered kidneys, such as kidney cysts, hydronephrosis or tumours [48]. Quantitative and qualitative scintigraphic measurement of renal function are presently applied in practice [49]. Determination of the kidney's glomerular filtration rate (GFR) is often taken into account in surgical planning. Only scintigraphy has the ability to measure individual kidney function. It is of importance in case of planned surgical nephrotomy or nephrectomy.

As in humans, nuclear medicine techniques may be useful in evaluating acute renal allograft rejection in dogs and cats, although there is a debate on superiority of scintigraphic over radiographic findings in those patients [50].

Infection and inflammation

99mTc-HMPAO-labelled leukocytes scintigraphy is an effective tool for the diagnosis of orthopaedic infection as a cause of lameness in horses [51].

99mTc-HMPAO-labelled leukocytes were also used in assessing small intestinal malabsorption in horses. Intestinal uptake of activity was detected in 12 of the 17 cases, but in none of the control horses. The technique was therefore specific for intestinal pathology, but failed to detect some horses that might have had intestinal pathology. No indications of the horses' specific pathology were obtained, and their prognosis or response to treatment could not be predicted [52].

99mTc-labeled radiopharmaceutical ciprofloxacin can be used in dogs to reveal the site of an infection [53].

Imaging — miscellanea

Some data might be available from feline hysteroscintigraphy. These findings demonstrated that fluids or particles deposited in the vagina of the cat could be transported into the uterus during some stages of the oestrous cycle. The fluoroscopic and scintigraphic techniques may be further modified to permit more detailed studies of uterine contractile patterns and sperm transport in the feline female reproductive tract. The information on cervical patency is also of value for the development of techniques for artificial insemination in this species, and should also be studied in the ovulatory cycle [54].

Radionuclide therapy

Radionuclide therapy of hyperthyreosis in cats is reviewed above. High fixed doses (more than 1000 MBq) were used in cats after surgical removal of thyroid carcinoma [55].

Bone and joints

153-Sm-EDTMP has been experimentally used in veterinary medicine for more than a decade to treat bone tumours and to provide bone pain palliation [56, 57]. Lattimer and co-workers, after extensive studies in normal dogs [56], applied 153-Sm-EDTMP in forty dogs with bone tumours [57]. Bone pain palliation occurred in most cases. Remarkably, there were complete regressions of some tumours. During the following years, Milner and co-workers from South Africa [58], and Moe and Aas from Norway applied 153-samarium in treating osteosarcomas [59, 60]. Their results include the complete regression of tumours in 2 out of 9 treated dogs. However, in other patients, the palliative effect of radionuclide therapy could sparsely be documented.

Radionuclide synovectomy may be applied in horses with good results, although a "flare" phenomenon may last for up to 72 hours [61]. In animals, radiosynovectomy using 166-holmium ferric hydroxide macro-aggregate or 153-samarium bound to hydroxyapatite microspheres and 90-yttrium silicate may be considered as a supportive therapeutic option for inflamed joints with synovial lining hyperplasia. It should preferably be used in combination with pharmacological treatment and/or physical therapy in cases of osteoarthritis prior to surgery or joint replacement [62].

Ophtalmology

Corneal pannus was shown to respond to radiation therapy with Sr-90, and long-term benefits can be achieved. Side effects are minimal. Optimal sequencing of therapy and dosage still has to be examined [63]. Good results were reported following the implantation of gold-198 seeds with 65 Gy by local delivery in cat's eyelid carcinoma [64].

Radionuclide therapy — varia

Attempts were made to treat essential thrombocytaemia, with promising results [65].

Staff and equipment

Veterinary dedicated medical equipment dates back to the eighties [66]. It required a specially constructed gantry, with a head on a long arm, to enable the imaging of heads and legs in horses. Today, now that nuclear medicine department are numerous, either in veterinary hospitals or outpatients practices, there exists dedicated veterinary PET equipment, with large stationary gantries enabling large animals to be scanned. On some occasions, gammacameras originally suited for humans are regenerated and reconstructed for animal studies either by extension the arm of the gammacamera's head or by constructing a special large gantry to enable the study of large animals.

Radioprotection of veterinary staff is not a major problem within the legislated limits for whole body doses, caution should be paid to secure radioactive waste secondary to urine radionuclide excretion [67].

Concluding remarks

As shown above, veterinary nuclear medicine is an interesting entity, covering most fields of interest of radionuclide diagnostics in humans. Veterinary nuclear medicine is very popular in the USA and its popularity in Europe is growing. As mentioned in the introduction, in Central Europe it is not very popular, and scientific activity is in fact limited the to the group of Dr. L. Balogh from Budapest. This situation should be changed for the benefit of local nuclear medicine communities.

References

1. [no authors listed] The use of radioisotopes in veterinary science. Br Vet J 1966; 122: 1–2.
2. Harris AL. Radioisotope photoscanning in the dog. Vet Med Small Anim Clin 1968; 63: 1038–1039.
3. Steckel RR. The role of scintigraphy in the lameness evaluation. Vet Clin North Am Equine Pract 1991; 7: 207–239.
4. Koblik PD, Hornof WJ, Seeherman HJ. Scintigraphic appearance of stress-induced trauma of the dorsal cortex of the third metacarpal bone in racing Thoroughbred horses: 121 cases (1978–1986). J Am Vet Med Assoc 1988; 192: 390–395.
5. Davidson EJ, Martin BB Jr. Stress fracture of the scapula in two horses. Vet Radiol Ultrasound 2004; 45: 407–410.
6. Seeherman HJ, Morris E, O'Callaghan MW. The use of sports medicine techniques in evaluating the problem equine athlete. Vet Clin North Am Equine Pract 1990; 6: 239–274.
7. Ross MW, Maxson AD, Stacy VS, Buchanan KB. First-pass radionuclide angiography in the diagnosis of aortoiliac thromboembolism in a horse. Vet Radiol Ultrasound 1997; 38: 226–230.
8. Schwarz T, Johnson VS, Voute L, Sullivan M. Bone scintigraphy in the investigation of occult lameness in the dog. J Small Anim Pract 2004; 45: 232–237.
9. Kippenes H, Johnston G. Diagnostic imaging of osteochondrosis. Vet Clin North Am Small Anim Pract 1998; 28: 137–160.
10. Laflin SL, Steyn PF, VanMetre DC, Uhrig JL, Callan RJ. Evaluation and treatment of decreased libido associated with painful lumbar lesions in two bulls. J Am Vet Med Assoc 2004; 224: 565–570.
11. Jorda C, Matis U, Bone scintigraphy: an early indicator of disease or the last hope for a diagnosis? 12th European Society of Veterinary Orthopedics and Traumatology Congress, Munich, Germany, September 10–12, 2004.
12. Jorgensen JS, Geoly FJ, Berry CR, Breuhaus BA. Lameness and pleural effusion associated with an aggressive fibrosarcoma in a horse. J Am Vet Med Assoc 1997; 210: 1328–1331.
13. Leibman NF, Kuntz CA, Steyn PF et al. Accuracy of radiography, nuclear scintigraphy, and histopathology for determining the proximal extent of distal radius osteosarcoma in dogs. Vet Surg 2001; 30: 240–245.
14. Stimson EL, Cook WT, Smith MM, Forrester SD, Moon ML, Saunders GK. Extraskeletal osteosarcoma in the duodenum of a cat. J Am Anim Hosp Assoc 2000; 36: 332–336.
15. Peremans K, Otte A, Verschooten F, Van Bree H, Dierckx R. Soft tissue metastasis of an osteosarcoma of the humerus in a four-legged patient. Eur J Nucl Med Mol Imaging 2003; 30: 188.
16. Krzemiński M, Lass P, Teodorczyk J. An interesting image — 99m--EHDP accumulation in soft tissue sarcoma of the dog. Nucl Med Rev 2004; 7.
17. Kvinnsland Y, Bruland O, Moe L, Skretting A. A method for measurement of the uptake patterns in the two beta emitting radionuclides in the same tissue section with a digital detector: application to a study of 89Sr and 153Sm-EDTMP dog with spontaneous osteosarcoma. Eur J Nucl Med Mol Imaging 2002; 29: 191–197.
18. Haines DM, Bruland OS, Matte G, Wilkinson AA, Meric SM, Fowler JD. Immunoscintigraphic detection of primary and metastatic spontaneous canine osteosarcoma with F(ab')2 fragments of osteosarcoma-associated monoclonal antibody TP-1. Anticancer Res 1992; 12: 2151–2157.
19. Balogh L, Andocs G, Perge E et al. Oncological scintigraphy in dogs with 99mTechnetium MIBI and DMSA(V) — two case reports. Vet Q 2001; 23: 52–56.
20. Balogh L, Thuroczy J, Andocs G et al. Sentinel lymph node detection in canine oncological patients. Nucl Med Rev 2002; 5: 139–144.
21. Gordon JM, Ehrhart EJ, Sisson DD, Jones MA. Juvenile hyperthyroidism in a cat. J Am Anim Hosp Assoc 2003; 39: 67–71.
22. Sjolemma BE, Pollak YWEA, van den Brom WE et al. Thyroidal radioidine uptake in hyperthyreoid cats. Vet Q 1989; 11: 165–170.
23. Mooney CT. Feline hyperthyroidism. Diagnostics and therapeutics. Vet Clin North Am Small Anim Pract 2001; 31: 963–983.
24. Peterson ME, Becker DV. Radioiodine thyroid imaging inn 135 cats with hyperthyroidism. Vet Radiol 1984; 25: 23.
25. Theon AP, Van Vechten MK, Feldman E. Prospective randomized comparison of intravenous versus subcutaneous administration of radioiodine for treatment of hyperthyroidism in cats. Am J Vet Res 1994; 55: 1734–1738.
26. Slater MR, Komkov A, Robinson LE et al. Long-term follow-up of hyperthyroid cats treated with iodine-131. Vet Radiol Ultrasound 1994; 35: 205.
27. Jones BR, Cayzer J, Dillon EA et al. Radio-iodine treatment of hyperthyroid cats. NZ Vet J 1991; 39: 71.
28. Mooney CT. Radioactive iodine therapy for feline hyperthyroidism: efficacy and administration routes. J Small Anim Pract 1994; 35: 289.
29. Craig A, Zuber M, Allan Gs. A prospective study of 66 cases of feline hyperthyreoidism treated with a fixed dose of intravenous ^{131}I. Aust Vet Pract 1993; 23: 2.
30. Adams WH, Daniel GB, Legendre AM, Gompf RE, Grove CA. Changes in renal function in cats following treatment of hyperthyroidism using 131I. Vet Radiol Ultrasound 1997; 38: 231–238.
31. Feeney DA, Jessen CR, Weichselbaum RC, Cronk DE, Anderson KL. Relationship between orally administered dose, surface emission rate for gamma radiation, and urine radioactivity in radioiodine-treated hyperthyroid cats. Am J Vet Res 2003; 64: 1242–1247.
32. Puille M, Knietsch M, Spillmann T, Grunbaum EG, Bauer R.Radioiodine treatment of feline hyperthyroidism in Germany. Nuklearmedizin 2002; 41: 245–251.
33. Kintzer PP, Peterson ME Nuclear medicine of the thyroid gland. Scintigraphy and radioiodine therapy Vet Clin North Am Small Anim Pract 1994; 24: 587–605.
34. Branam JE, Leighton RL, Hornof WJ Radioisotope imaging for the evaluation of thyroid neoplasia and hypothyroidism in a dog. J Am Vet Med Assoc 1982; 180: 1077–1079.
35. Peterson ME, Kintzer PP, Hurley JR, Becker DV. Radioactive iodine treatment of a functional thyroid carcinoma producing hyperthyroidism in a dog. J Vet Intern Med 1989; 3: 20–25.
36. Matwichuk CL, Taylor SM, Wilkinson AA et al. Use of technetium Tc-99m sestamibi for detection of a parathyroid adenoma in a dog

with primary hyperparathyroidism. J Am Vet Med Assoc 1996; 209: 1733–1736.
37. Altschul M, Simpson KW, Dykes NL, Mauldin EA, Reubi JC, Cummings JF. Evaluation of somatostatin analogues for the detection and treatment of gastrinoma in a dog. J Small Anim Pract 1997; 38: 286–291.
38. Lester NV, Newell SM, Hill RC, Lanz OI. Scintigraphic diagnosis of insulinoma in a dog. Vet Radiol Ultrasound 1999; 40: 174–178.
39. Devaux JY, Cabane L, Esler M, Flaouters H, Duboc D. Non-invasive evaluation of the cardiac function in golden retriever dogs by radionuclide angiography. Neuromuscul Disord 1993; 3: 429–432.
40. Morandi F, Daniel GB, Gompf RE, Bahr A. Diagnosis of congenital cardiac right-to-left shunts with 99mTc-macroaggregated albumin. Vet Radiol Ultrasound 2004; 45: 97–102.
41. Pouchelon JL, Chetboul V, Devauchelle P, Delisle F, Mai W, Vial V. Diagnosis of pulmonary thromboembolism in a cat using echocardiography and pulmonary scintigraphy. J Small Anim Pract 1997; 38: 306––310.
42. O'Callaghan MW. Nuclear imaging techniques for equine respiratory disease. Vet Clin North Am Equine Pract 1991; 7: 417–433.
43. Tillson DM, Winkler JT. Diagnosis and treatment of portosystemic shunts in the cat. Vet Clin North Am Small Anim Pract 2002; 32: 881––899.
44. Lofstedt J, Koblik PD, Jakowski RM, McMillan MC, Engelking LR. Use of hepatobiliary scintigraphy to diagnose bile duct atresia in a lamb. J Am Vet Med Assoc 1988; 193: 95–98.
45. Boothe HW, Boothe DM, Komkov A, Hightower D. Use of hepatobiliary scintigraphy in the diagnosis of extrahepatic biliary obstruction in dogs and cats: 25 cases (1982–1989). J Am Vet Med Assoc 1992; 201: 134–141.
46. Newell SM, Graham JP, Roberts GD et al. Quantitative hepatobiliary scintigraphy in normal cats and in cats with experimental cholangiohepatitis. Vet Radiol Ultrasound 2001; 42: 70–76.
47. Rothuizen J, van den Brom WE Quantitative hepatobiliary scintigraphy as a measure of bile flow in dogs with cholestatic disease. Am J Vet Res 1990; 51: 253–256.
48. Meyer-Lindenberg A, Westhoff A, Wohlsein P, Nolte I. Validity of diagnostic methods for kidney function tests in the cat. Tierarztl Prax 1996; 24; 4: 395–401.
49. Kampa N, Wennstrom U, Lord P et al. Effect of region of interest selection and uptake measurement on glomerular filtration rate measured by 99mTc-DTPA scintigraphy in dogs. Vet Radiol Ultrasound 2002; 43: 383–391.
50. Halling KB, Graham JP, Newell SP et al. Sonographic and scintigraphic evaluation of acute renal allograft rejection in cats. Vet Radiol Ultrasound 2003; 44: 707–713.
51. Long CD, Galuppo LD, Waters NK, Hornof WJ. Scintigraphic detection of equine orthopedic infection using Tc-HMPAO labelled leukocytes in 14 horses. Vet Radiol Ultrasound 2000; 41: 354–359.
52. Menzies-Gow NJ, Weller R, Bowen IM et al. Use of nuclear scintigraphy with 99mTc-HMPAO-labelled leucocytes to assess small intestinal malabsorption in 17 horses. Vet Rec 2003; 153: 457–462.
53. Peremans K, De Winter F, Janssens L, Dumont F, Van Bree H, Dierckx R. An infected hip prosthesis in a dog diagnosed with a 99mTc-ciprofloxacin (Infecton) scan. Vet Radiol Ultrasound 2002; 43: 178–182.
54. Chatdarong K, Kampa N, Axner E, Linde-Forsberg C. Investigation of cervical patency and uterine appearance in domestic cats by fluoroscopy and scintigraphy. Reprod Domest Anim 2002; 37: 275–281.
55. Guptill L, Scot-Moncrieff CR, Janowitz EB et al. Response to high dose radioactive iodine administration in cats with thyroid carcinoma that had previously undergone surgery. JAVMAQ 1995; 207: 1055–1058.
56. Lattimer JC, Corwin LA Jr, Stapleton J, Volkert WA, Ehrhardt GJ, Ketring AR, Hewett JE, Simon J, Goeckeler WF. Clinical and clinicopathologic effects of samarium-153-EDTMP administered intravenously to normal beagle dogs. J Nucl Med 1990; 31: 586–593.
57. Lattimer JC, Corwin LA Jr, Stapleton J et al. Clinical and clinicopathologic response of canine bone tumor patients to treatment with samarium-153-EDTMP. J Nucl Med 1990; 31: 1316–1325.
58. Milner RJ, Dormehl I, Louw WK, Croft S. Targeted radiotherapy with Sm-153-EDTMP in nine cases of canine primary bone tumours. J S Afr Vet Assoc 1998; 69: 12–17.
59. Moe L, Boysen M, Aas M, Lonaas L, Gamlem H, Bruland OS. Maxillectomy and targeted radionuclide therapy with 153Sm-EDTMP in a recurrent canine osteosarcoma. J Small Anim Pract 1996; 37: 241–246.
60. Aas M, Moe L, Gamlem H, Skretting A, Ottesen N, Bruland OS. Internal radionuclide therapy of primary osteosarcoma in dogs, using 153Sm-ethylene-diamino-tetramethylene-phosphonate (EDTMP). Clin Cancer Res 1999; 5 (Suppl 10): 3148s–3152s.
61. Yarbrough TB, Lee MR, Hornof WJ, Schumacher HR Jr., O'Brien TR. Evaluation of samarium-153 for synovectomy in an osteochondral fragment-induced model of synovitis in horses. Vet Surg 2000; 29: 252–263.
62. Linke R. Radiosynovectomy: a radionuclide therapy of osteoarthritis? 12th European Society of Veterinary Orthopedics and Traumatology Congress, Munich, Germany September 10–12, 2004.
63. Hoecht S, Gruning G, Allgoewer I, Nausner M, Brunnberg L, Hinkelbein W. Treatment of keratitis superficialis chronica of the dog with strontium 90. Strahlenther Onkol 2002; 178: 99–104.
64. Hardman C, Stanley R.Radioactive gold-198 seeds for the treatment of squamous cell carcinoma in the eyelid of a cat. Aust Vet J. 2001; 79: 604–608.
65. Hopper PE, Mandell CP, Turrel JM, Jain NC, Tablin F, Zinkl JG. Probable essential thrombocythemia in a dog. J Vet Intern Med 1989; 3: 79–85.
66. Attenburrow DP, Portergill MJ, Vennart W. Development of an equine nuclear medicine facility for gamma camera imaging. Equine Vet J 1989; 21: 86–90.
67. Whitelock RG. Radiation hazards from horses undergoing scintigraphy using technetium-99m. Equine Vet J 1997; 29: 26–30.